*Environmental Chemistry*OCCURRENCE OF SYNTHETIC MUSK FRAGRANCES IN HUMAN BLOOD
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Abstract—We measured two nitro musk fragrances (musk xylene) and musk ketone) and five polycyclic musk fragrances (galaxolide [HHCB], tonalide [AHTN], celestolide [ADBI], traseolide [ATII], and phantolide [AHMI]) in human blood samples from 11 cities of China ($n = 204$). Possible temporal trends in musk concentrations and associations with personal factors, such as gender, age, and others, were studied. Galaxolide (HHCB) showed the highest median concentration (0.85 ng/g) followed by AHTN (0.53 ng/g) with high detection frequency (91 and 77%, respectively). Concentrations of the other synthetic musk fragrances, including musk ketone and musk xylene, were all below the quantification limits. The results suggested that musk concentrations were not significantly relative to gender and body weight but positively correlated with age groups and locations. Apparent differences were also observed in the ratios of HHCB to AHTN concentrations among different cities. *Environ. Toxicol. Chem.* 2010;29:1877–1882. © 2010 SETAC

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INTRODUCTION

Synthetic musk fragrances (SMs) have been widely used as a substitute for natural musks and can be found in a variety of personal care products such as washing, cleaning, consumer goods, and technical products such as fish baits, additives for cigarettes and food, herbicide formulations, and explosives [1]. The main classes of synthetic musk fragrances are nitro musk compounds, such as musk xylene (MX) and musk ketone (MK), and polycyclic musk compounds, including galaxolide (HHCB), tonalide (AHTN), celestolide (ADBI), traseolide (ATII), and phantolide (AHMI). Nitro musk fragrances had been decreasingly used in the 1990s, because some of them were found to be persistent, bioaccumulative, and even biologically toxic [2,3]. In Japan, nitro musks are under a total ban. In the United States it is forbidden to add MX to cosmetic products. In 1993, the German detergent industry voluntarily stopped using MX in their products [4,5]. Now, only a small amount of MK and MX is still used, and it is reported that HHCB, AHTN, MK, and MX represent approximately 95% of the market in Europe for all nitro and polycyclic musk fragrances [2,6]. In China, the use of nitro musk fragrances were also restricted by the Chinese government according to the Tenth Five-Year Plan of Light Industry in 2001 [7].

In recent years, more and more studies have reported the occurrence of nitro- and polycyclic musk fragrances in various environmental matrixes, such as sewage sludge, air, wastewater, and sediment [8–11] as well as fish, human tissues, mother's milk [12–15], and others. However, there is little information about temporal trends of synthetic musk compounds concentrations in human blood that may reflect the

changes in use of these compounds by the industry and alterations in the patterns of consumer use of perfumed products. To our knowledge, the first study was presented on musk xylene in blood samples by Helbling in 1994 [16]. In the following years, only a few studies have been reported about blood concentrations on musks by Angerer in 1997 [17], Bauer in 1999 [18], Kuklenyik et al. in 2007 [19], and Hutter et al. in 2005 [20] and 2009 [21], respectively.

In China, HHCB and AHTN were found at higher concentration levels than other synthetic musk fragrances in different matrixes. Zhou et al. [22] studied the distribution and elimination of polycyclic musk fragrances in three sewage treatment plants of Beijing. Zeng et al. [23,24] detected HHCB and AHTN in sewage sludge, influents, and effluents from wastewater treatment plants of Guangdong province and Shanghai, as well as in sediment from Suzhou Creek [24]. Moreover, Zeng et al. [25] investigated the distribution of polycyclic musks in surface sediment of the Pearl River Delta and Macao Coastal Region. The results indicated the widespread contamination of synthetic musk fragrances in the marine environment in China. The existence of synthetic musk fragrances in fish tissues of Chinese sturgeon has been verified by Hu et al. [26]. Thus far, no study exists on the occurrence of synthetic musk fragrances in humans, such as in blood, human tissues, and mother's milk, in China.

In the present study, seven synthetic musk fragrances in human blood samples were analyzed, including five polycyclic musks (HHCB, AHTN, ADBI, AHMI, and ATII) and two nitro musks (MK and MX). The samples were obtained from 204 individuals from 11 Chinese cities (11 provinces). The purpose of the present study was to understand the geographical patterns of synthetic musk fragrances in China and provide data on the occurrence of nitro and polycyclic musk fragrances in human blood from the Chinese people. The relationships between musk concentrations and personal factors of donors, such as age,

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weight, and gender, were also examined, which have been shown to be associated with levels of other persistent organic compounds in humans.

MATERIALS AND METHODS

Materials and reagents

The standard solutions containing AHTN (7-acetyl-1,1,3,4,4,6-hexamethyl-1,2,3,4-tetrahydronaphthalene), HHCb (1,3,4,6,7,8-hexahydro-4,6,6, 7, 8, 8-hexamethylcyclopenta (g)-2-benzopyran), ADBI (4-acetyl-1,1-dimethyl-6-tert-butylindan), AHMI (6-acetyl-1,1,2,3,3,5-hexamethylindan), ATII (5-acetyl-1,1,2,6-tetramethyl-3-isopropylindan), MK, and MX were obtained from Dr. Ehrenstorfer (Augsburg, Germany). Surrogate standard d_{10} -fluoranthene was purchased from Supelco, and internal standard hexachlorobenzene (HCB) $^{13}\text{C}_6$ was from Dr. Ehrenstorfer. Dichloromethane (DCM), *n*-hexane, acetone of high-performance liquid chromatography grade were purchased from J.T. Barker. Anhydrous sodium sulfate was baked at 450°C for 5 h prior to use. Silica gel (100–200 mesh) was treated at 150°C for 12 h and deactivated with 2% water; this should be used within 3 d.

Sample collection

As shown in Figure 1, 11 cities, including Harbin (45°45'N, 126°41'E), Qingdao (36°04'N, 120°18'E), Huhhot (40°49'N, 111°48'E), Chongqing (29°32'N, 106°32'E), Chengdu (30°39'N, 104°05'E), Lanzhou (36°03'N, 103°49'E), Kunming (25°00'N, 102°41'E), Guiyang (26°35'N, 106°42'E), Ningbo (29°52'N, 121°31'E), Shijiazhuang (38°02'N, 114°28'E), and Changsha (28°11'N, 113°00'E), were selected for sampling. Through the blood centers in each city, blood samples collected with Vacuette plasma tubes (coated with sodium heparin) were obtained from 204 donors between November 2007 and May 2008 from ages 17 to 75 years. Blood samples were stored in a refrigerator at –20°C until analysis. Age, body weight, gender, and locations of each donor were recorded. Furthermore, subjects were asked how often they smoked, how often they used body-care products, and how often they ate fish.

Sample extraction

The samples (2 ml) were defrosted and the surrogate standard (15 μl of a 100- $\mu\text{g/L}$ solution of deuterated d_{10} -fluoranthene in acetone) was added. Precipitation of the proteins was performed using ethanol (1 ml) under vigorous mixing, then 2 ml *n*-hexane was added shaking for 2 min followed by centrifugation for 5 min at 3,000 rpm; finally, the hexane phase was withdrawn to a new glass tube. The extraction was repeated with *n*-hexane (2 ml). The entire procedure was repeated twice. The combined *n*-hexane phases were concentrated to 1 ml and passed through a glass chromatography column (1 cm inner diameter, 15 cm length), which was fitted with Teflon® stopcock and packed consecutively with glass wool, 0.7 g silica gel, and 0.5 g anhydrous sodium sulfate (after activation and deactivation, see section *Materials and Reagents*) for cleaning. The column was conditioned with 5 ml *n*-hexane, 5 ml dichloromethane, and 5 ml *n*-hexane successively before use. Elution was performed with *n*-hexane (8 ml), hexane/dichloromethane (1:3) (12 ml), and hexane/dichloromethane (1:4) (8 ml). The combined eluate was collected and concentrated to 1 ml. Prior to gas chromatography-mass spectrometry (GC-MS) analysis, the internal standard (HCB) $^{13}\text{C}_6$ was added.

Instrumental analysis

The GC-MS analysis was performed using an HP7890GC/5975MSD system with electron ionization and a quadrupole mass detector using selected ion monitoring (SIM) mode (Agilent). The ions monitored for ADBI were m/z 229, 224, and 173; for AHMI, m/z 229, 224, and 187; for HHCb, m/z 243, 258, and 213; for AHTN, m/z 243, 258, and 148; for ATII, m/z 215, 258, and 173; for MX, m/z 282, 297, and 207; and for MK, m/z 279 and 294. The first ion in each group was used for quantification. In addition, the ions for d_{10} -fluoranthene and HCB- c_{13} were m/z 212 and 290, respectively. A 30-m 5% phenyl methyl siloxane capillary column (HP-5MS; 0.25 mm inner diameter 0.25- μm film thickness) was used for separation of target analytes. The operating conditions were as follows: column temperature programmed from 90°C (2 min) to 170°C at 10°C/min, then to 180°C at 1°C/min followed by 30°C/min to 270°C (7 min isothermal). One microlitre was injected splitless

Fig. 1. Sampling locations in China. (1) Haerbin; (2) Huhehaote; (3) Shijiazhuang; (4) Qingdao; (5) Ningbo; (6) Changsha; (7) Guiyang; (8) Kunming; (9) Chongqing; (10) Chengdu; (11) Lanzhou.

at 250°C. Transfer line temperature was 280°C, and source temperature was 230°C.

Quality control and quality assurance

To correct the losses of analytes during the sample pretreatments and variations of instrument response between every injection, a surrogate standard and an internal standard were used. In the present study, *d*₁₀-fluoranthene was used as a surrogate standard, which was also adopted by other researchers because the compound showed similar physicochemical properties with musks such as logarithm octanol–water partition coefficient (5.22 for *d*₁₀-fluoranthene [6] and 4–6 for musks [26,27]). To verify the suitability of *d*₁₀-fluoranthene as a surrogate standard for all of synthetic musk compounds during the above pretreatment, the recovery experiments (1.5 µg/L, *n* = 6) were conducted. The results showed that the recoveries of the surrogate standard were in the range of 85.0 to 120.0%. The internal standard HCB ¹³C₆ was used to quantify in sample extracts. All the recoveries of analytes had been corrected using *d*₁₀-fluoranthene.

For calibration purposes, six different concentrations of synthetic musk compounds were analyzed by GC-MS. A standard calibration was performed. Correlation coefficient *R*² are >0.99. Matrix spike recovery studies were carried out. Recoveries of seven spiked synthetic musk fragrances (2 ng each of standards) ranged from 77.9 to 118.5%, with the relative standard deviation in the range of 1.5 to 9.5%.

To avoid possible contamination, all glassware was soaked in K₂Cr₂O₇-H₂SO₄ lotion for at least 12 h, and all equipment was rinsed with acetone in advance. A procedural blank was processed with each batch of eight samples, and *n*-hexane was injected before the sample sequence. Furthermore, a field blank was included during the sampling in each city. All synthetic musk fragrances concentrations were below detection limits in all of the blank samples.

The limits of detection (LOD) were defined as the concentrations needed to produce a signal-to-noise ratio of 3:1 for measured SMs. The limits of quantification (LOQ) were set to twice the concentrations of LOD. The detection limit for HHCB, AHTN, AHMI, MX, and MK was 0.15 µg/L, and for ADBI and ATII was 0.13 µg/L.

Statistical analysis

Differences in synthetic musk compounds concentrations in blood samples between different groups (such as locations and age groups) were calculated using the nonparametric tests (a Kruskal-Wallis test). A Mann-Whitney *U* test was used to assess the differences in concentrations of SMs in blood samples between genders. A *p* value below 0.05 was considered significant. Undetectable concentration was assigned a value equal to the LOD divided by the square root of 2. All statistical analyses were performed by the SPSS software, version 13.0 (SSPS).

RESULTS AND DISCUSSION

Among 204 donors of 11 cities, 94 were female and 110 were male. The age ranged from 17 to 75 years, with a median age of 25 years, and the median ages for female and male were 27 and 24 years, respectively.

Musk concentrations

Two polycyclic musk compounds, HHCB and AHTN, were identified at higher percentages of the blood samples in all the

cities. Galaxolide (HHCB) was detected in 98% of the samples (nearly all of them >LOQ) and AHTN in 85% of the samples (77% >LOQ). The values were higher than those reported by Hutter et al. [20], especially for AHTN, which was only 17% in their study. Moreover, Hutter et al. [20] showed that the median and maximum HHCB concentrations were 0.42 and 4.1 µg/L in plasma levels, respectively. Similar with their results, the maximum concentration for HHCB was 1.63 µg/L in whole blood level. However, the median concentration in the present study was higher up to 0.85 µg/L. As for AHTN, the median and maximum concentrations in the present study were also much higher than those reported by Hutter et al. [20]. In their study, the median value was below the LOD and the maximum concentration was 0.8 µg/L in plasma levels, whereas we found that the median and maximum values for AHTN were 0.53 and 1.29 µg/L in whole blood levels, respectively.

All other synthetic musk fragrances including MX and MK were below the detection limits in all blood specimens in the present study. The change of MX in European countries in blood samples had been studied for the past 30 years. In 1994, MX was first measured by Helbling [16], and ranged from 12 to 49 ng/g. A few years later, the concentration of MX was detected to be 0.1 to 1.12 ng/g by Angerer in 1997 [17]. In 1999, Kafferlein [5] reported a remarkable decrease of MX concentration by comparing the values among 1992/1993 and 1998. The change was consistent with the decreased use of MX in European countries. Similarly, the low concentrations of MX and MK in the present study seemed in accordance with the regulations presented in the Tenth Five-Year Plan of China Light industry in 2001 [7] that restricted the use of nitro musk fragrances.

Gender and age

To investigate possible gender influence on blood SMs level, a Mann-Whitney *U* test was conducted. However, no significant gender-related statistical difference was observed in the concentrations of HHCB and AHTN (*p* > 0.05) (see Fig. 2). These accumulation characteristics were similar to those reported in fish tissues by Duedahl-Olesen et al. [28]. Kannan [12] also found no relationship between gender and the concentrations of HHCB or AHTN in human fat samples. However, Hutter et al. [20] observed that plasma concentrations of HHCB were significantly higher in the blood of women than those in men, and they attributed this difference to the more frequent use of creams, body lotions, and perfumes by women than men.

To investigate age influence on the concentrations of musks in human blood, a Kruskal-Wallis test and a regression analysis were conducted. Although concentrations of HHCB and AHTN were found to increase with age, no significant statistical relationship could be discerned according to regression analysis (*p* > 0.05). The features were similar to those reported in human adipose and mother's milk [14]. However, the different age groups in female samples had a statistical significance with concentrations of HHCB according to Kruskal-Wallis test (*p* < 0.05). As shown in Figure 3, females between 27 and 40 years of age showed lower HHCB concentrations levels than younger or older females. The feature was similar to those reported by Hutter et al. [20], that plasma concentrations of HHCB were significantly higher in younger individuals (19–25 years) compared to the older individuals (26–43 years). Nevertheless, we did not find such a similar age-related concentration pattern in the blood of men. We tried to seek the cause of the lower concentrations in women between 27 and 40 years of age. It was reported that the first-time mothers were

Fig. 2. Boxes and whisker plots showing the concentrations of galaxolide (HHCB) and tonalide (AHTN) in human blood, stratified by gender. Boxes show 25th and 75th percentiles and median. Whiskers show the lowest and highest concentrations. The circles outside the whiskers represent observations outside the $1.5 \times$ interquartile range.

on the average age of 26 to 29 years in western, northern, and southern Europe. In the United States, the average age of the woman's first childbirth was 25 in 2006 ([29]; <http://www.un.org/esa/population/>) and 26.6 in 2007 in China [30]. Thus, many women would have at least one baby when they were 26 to 40 years old. However, it was reported that mass transfer of accumulated lipophilic contaminants from mother to fetus would be a factor to influence the accumulation of organochlorines, dioxins, butyltin compounds [31–33], as well as synthetic musk fragrances [26]. Moreover, musks were verified detectable in a mother's milk [14]. Therefore, the phenomena of the lower HHCB concentrations in women aged 27 to 40 years may be because of the fact that the women in the age group were generally in lactation, and the synthetic musk compounds may be transferred to their children.

Other personal characteristics

Other personal characteristics that might influence the plasma concentrations of synthetic musk fragrances include smoking, use of perfumed products, fish consumption, and others. In the present study, smoking was found not to be associated with synthetic musk compounds concentrations in

human blood ($p > 0.05$). Similarly, Lignell et al. [14] also observed no association between smoking habits and musk concentrations in mother's milk; however, they reported a significant positive association between use of perfumed products and concentrations of HHCB and AHTN in mother's milk. Hutter et al. [20] also indicated that persons using creams frequently showed high plasma concentrations of HHCB. All the information on the use of body-care products was not clear, and the discussion was not conducted in the present study. However, we investigated the body weight influence on concentrations of HHCB and AHTN in human blood, and no apparent difference was found ($p > 0.05$). Moreover, Hutter et al. [20] showed that the fish consumption habits was an important influence factor to concentrations of HHCB and AHTN, whereas Angerer [17] suggested no relationships between the fish consumption habits and the concentrations of MX in human plasma. Because all the information on fish consumption habits of the 204 samples was not clear, the conclusion was not provided in the present study.

Geographical trends

According to the above results, musk concentrations were not positively relative to gender, as well as age or age group in male blood samples. Therefore, it is reasonable to investigate the influence of locations on musk concentrations based on the 110 male blood samples. According to a Kruskal-Wallis test, concentrations of HHCB and AHTN were significantly correlated with locations ($p < 0.001$). As shown in Figure 4, the highest median concentration of HHCB was obtained from Harbin followed by Changsha, and the lowest was from Huhhot. It can be noted that the highest median concentration of AHTN was also obtained from Harbin followed by Changsha, and the median concentration in Huhhot was also lowest except Shijiazhuang. The phenomena suggested that musk concentrations in human blood in Changsha and Harbin were the highest, whereas in Huhhot they were the lowest among 11 cities. Moreover, a significant positive relationship was found between concentrations of HHCB and AHTN ($p < 0.001$) in human blood (Fig. 5), which indicated the coexposure of humans to the two synthetic musk compounds in China.

In the present study, the overall median concentration of AHTN was approximately twofold (2.3) lower than that of HHCB. A different ratio of HHCB to AHTN concentrations

Fig. 3. Relationship between age group and concentrations of galaxolide (HHCB) in female blood samples from China. 1, 2, and 3 represent age groups below 26 years, between 26 and 40 years, and above 40 years, respectively. The circles outside the whiskers represent observations outside the $1.5 \times$ interquartile range.

Fig. 4. Relationship between locations and concentrations of galaxolide (HHCB) and tonalide (AHTN) in male blood samples from China. The asterisk symbol (*) denotes extreme values, which were beyond the triplication of the difference between 25th and 75th percentiles. The circles represent singular values.

Fig. 5. Relationship between galaxolide (HHCB) and tonalide (AHTN) concentrations in human blood samples from China.

Fig. 6. Relationship between locations and ratios of galaxolide (HHCB) to tonalide (AHTN) concentrations. The asterisk symbol (*) denotes extreme values. The circle represents singular values.

(~4) was obtained in human fat samples collected from Austria by Kannan [12]. Peck and Hornbuckle [34] reported that the concentration ratio of HHCB to AHTN in Lake Michigan (USA) waters was 4.7. In China, it has been reported that the ratio of HHCB to AHTN concentrations was 5.3 in sewage sludge collected from the wastewater treatment plants in Guangdong province, and 1.46 in sediment samples from the Pearl River Delta [25]. To investigate the relationship between locations and ratios of HHCB to AHTN concentrations, a Kruskal-Wallis *U* test was conducted. The results showed that locations were significantly correlated with ratios of HHCB to AHTN ($p < 0.001$). As shown in Figure 6, the highest ratio was obtained from Kunming followed by Shijiazhuang, and the lowest ratio was achieved from Qingdao, where the concentrations of AHTN and HHCB were nearly equivalent. It should be mentioned that the ratios in Ningbo, Changsha, and Harbin were lower than those in other cities except Qingdao. It is possible that the phenomena could be caused by the different lifestyle and different donors' corporeity in the cities.

In summary, this is the first study to report the occurrence of synthetic musk fragrances in human blood in China. The results suggest the ubiquity of HHCB and AHTN and very low concentrations of other synthetic musk fragrances in human blood in China. The present study has not addressed the issue of risks from synthetic musk fragrances to humans and not clarified relationships between blood, human tissues, human milk, and excretion concentrations of synthetic musk fragrances. Further studies are needed to evaluate long-time toxicity of these compounds on humans and wildlife, and monitor the concentrations of these compounds in blood, fat, urine, and mother's milk.

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REFERENCES

- Klaschka U, Kolossa-Gehring M. 2007. Fragrances in the environment: Pleasant odours for nature? *Environ Sci Pollut Res* 14:44–52.
- Rimkus G, Rimkus B, Wolf M. 1994. Nitro musks in human adipose tissue and breast milk. *Chemosphere* 28:421–432.
- Bester K. 2009. Analysis of musk fragrances in environmental samples. *J Chromatogr A* 1216:470–480.
- Liehl B, Mayer R, Ommers S, Sönnichsen C, Koletzko B. 2000. Transition of nitro musks and polycyclic musks into human milk. In Berthold K, Kim FM, Olle H, eds, *Short and Long Term Effects of Breast Feeding on Child Health*, Vol 478—Medicine. Kluwer Academic, Moscow, Russia, pp 289–305.
- Käfferlein HU, Angerer J. 2001. Trends in the musk xylene concentrations in plasma samples from the general population from 1992/1993 to 1998 and the relevance of dermal uptake. *Int Arch Occup Environ Health* 74:470–476.
- Neff JM, Burns WA. 1996. Estimation of polycyclic aromatic hydrocarbon concentrations in the water column based on tissue residues in mussels and salmon: An equilibrium partitioning approach. *Environ Toxicol Chem* 15:2240–2253.
- State Economic and Trade Commission of China. 2001. *Tenth Five-year Plan of Industry and Development Strategies: State Economic and Trade Commission*. Economic Science Press, Beijing, China.
- Reiner J, Berset J, Kannan K. 2007. Mass flow of polycyclic musks in two wastewater treatment plants. *Arch Environ Contam Toxicol* 52:451–457.
- Kristin Quednow WP. 2008. Organophosphates and synthetic musk fragrances in freshwater streams in Hessen/Germany. *Clean Soil Air Water* 36:70–77.
- Simonich SL, Begley WM, Debaere G, Eckhoff WS. 2000. Trace analysis of fragrance materials in wastewater and treated wastewater. *Environ Sci Technol* 34:959–965.
- Einsle T, Paschke H, Bruns K, Schrader S, Popp P, Moeder M. 2006. Membrane-assisted liquid-liquid extraction coupled with gas chromatography-mass spectrometry for determination of selected polycyclic musk compounds and drugs in water samples. *J Chromatogr A* 1124:196–204.
- Kannan K, Reiner JL, Yun SH, Perrotta EE, Tao L, Johnson-Restrepo B, Rodan BD. 2005. Polycyclic musk compounds in higher trophic level aquatic organisms and humans from the United States. *Chemosphere* 61:693–700.
- Rimkus GG, Wolf M. 1996. Polycyclic musk fragrances in human adipose tissue and human milk. *Chemosphere* 33:2033–2043.
- Lignell S, Darnerud PO, Aune M, Cnattingius S, Hajslova J, Setkova L, Glynn A. 2008. Temporal trends of synthetic musk compounds in mother's milk and associations with personal use of perfumed products. *Environ Sci Technol* 42:6743–6748.
- Rimkus G, Rimkus B, Wolf M. 1994. Nitro musks in human adipose tissue and breast milk. *Chemosphere* 28:421–432.
- Helbing KS, Schmid P, Schlatter C. 1994. The trace analysis of musk xylene in biological samples: problems associated with its ubiquitous occurrence. *Chemosphere* 29:477–484.
- Angerer J, Käfferlein HU. 1997. Gas chromatographic method using electron-capture detection for the determination of musk xylene in human blood samples. *J Chromatogr B* 693:71–78.
- Bauer K, Frössl C. 1999. Blutkonzentrationen von polycyclischen und Nitromoschusverbindungen bei deutschen Probanden. *Umwelt Medizin Gesellschaft* 12:235–237.
- Kuklenyik Z, Bryant XA, Needham LL, Calafat AM. 2007. SPE/SPME-GC/MS approach for measuring musk compounds in serum and breast milk. *J Chromatogr B* 858:177–183.
- Hutter HP, Wallner P, Moshhammer H, Hartl W, Sattelberger R, Lorbeer G, Kundi M. 2005. Blood concentrations of polycyclic musks in healthy young adults. *Chemosphere* 59:487–492.
- Hutter HP, Wallner P, Moshhammer H, Hartl W, Sattelberger R, Lorbeer G, Kundi M. 2009. Synthetic musks in blood of healthy young adults: Relationship to cosmetics use. *Sci Total Environ* 407:4821–4825.
- Zhou HD, Huang X, Gao MJ, Wang XL, Wen XH. 2009. Distribution and elimination of polycyclic musks in three sewage treatment plants of Beijing, China. *J Environ Sci-China* 21:561–567.
- Zeng X, Sheng G, Gui H, Chen D, Shao W, Fu J. 2007. Preliminary study on the occurrence and distribution of polycyclic musks in a wastewater treatment plant in Guangdong, China. *Chemosphere* 69:1305–1311.
- Zhang XY, Yao Y, Zeng X, Qian G, Guo Y, Wu M, Sheng GY, Fu JM. 2008. Synthetic musks in the aquatic environment and personal care products in Shanghai, China. *Chemosphere* 72:1553–1558.
- Zeng XY, Sheng GY, Luo XJ, Shao WL, An TC, Fu JM. 2008. Distribution of polycyclic musks in surface sediments from the Pearl River Delta and Macao Coastal Region, South China. *Environ Toxicol Chem* 27:18–23.
- Wan Y, Wei QW, Hu JY, Jin XH, Zhang ZB, Zhen HJ, Liu JY. 2007. Levels, tissue distribution, and age-related accumulation of synthetic musk fragrances in Chinese Sturgeon (*Acipenser sinensis*): Comparison to organochlorines. *Environ Sci Technol* 41:424–430.
- Heberer T. 2002. Occurrence, fate and assessment of polycyclic musk residues in the aquatic environment of urban areas? *Acta Hydrochim Hydrobiol* 30:227–243.
- Duedahl-Olesen L, Cederberg T, Pedersen KH, Højgård A. 2005. Synthetic musk fragrances in trout from Danish fish farms and human milk. *Chemosphere* 61:422–431.
- Population Division of Department of Economic and Social Affairs of the United Nations. 2009. Child adoption: trends and policies. United Nations, New York, NY, USA.
- Chen W. 2008. Population change in China since reform and opening 30 years ago. *Populat Res* 32:18–29.
- Borrell A, Bloch D, Desportes G. 1995. Age trends and reproductive transfer of organochlorine compounds in long-finned pilot whales from the Faroe Islands. *Environ Pollut* 88:283–292.
- Iwata H, Watanabe M, Okajima Y, Tanabe S, Amano M, Miyazaki N, Petrov EA. 2004. Toxicokinetics of PCDD, PCDF and coplanar PCB congeners in Baikal seals, *Pusa sibirica*: age related accumulation, maternal transfer, and hepatic sequestration. *Environ Sci Technol* 38:3505–3513.
- Kim GB, Tanabe S, Iwakiri R, Tatsukawa R, Amano M, Miyazaki N, Tanaka H. 1996. Accumulation of butyltin compounds in Risso's dolphin (*Grampus griseus*) from the Pacific coast of Japan: comparison with organochlorines residue pattern. *Environ Sci Technol* 30:2620–2625.
- Peck AM, Hornbuckle KC. 2004. Synthetic musk fragrances in lake Michigan. *Environ Sci Technol* 38:367–372.